FACT SHEET

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PV Energy Payback and Greenhouse Gas Emissions: 2004 Status

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<u>Crystalline Silicon PV Modules on Rooftop applications</u>

With the cooperation of 11 European and US photovoltaic companies, an extensive effort was made to collect Life Cycle Inventory data that represent the current status of production technology for crystalline silicon modules. This type of module constitutes about 90% of the 1200 MW of PV system capacity installed in 2004. The new data cover all processes from the producing silicon feedstock to manufacturing cells and modules. All commercial wafer technologies are covered, that is multi- and mono-crystalline wafers, as well as ribbon technology. These data can be considered representative of the status of technology in 2004. [Alsema, De Wild-Scholten, MRS Fall meeting 2005].

With this information, we analyzed the environmental impacts of PV electricity generation, and demonstrated that the life-cycle greenhouse gas emissions of a rooftop PV system based on multicrystalline silicon and located in Southern-Europe (1700 kWh/m2-yr) is **only 35 g/kWh**. For silicon ribbon and monocrystaliine silicon technologies the respective numbers are 30 and 43 g/kWh. The energy payback times of such systems are, respectively, 1.6, 2.1, and 2.5 years for ribbon, multi-, and mono-Si technology. Furthermore, we estimated external costs using the baseline damage factor method developed within the Externe-Pol project. For a multi-Si system in S.-Europe the external cost would be **0.17 €c/kWh**, which is more than **70% lower** than a figure given in the last ExternE publication [Eur. Commission, 2004].

<u>Balance of system for Central Plant (on-ground installation)</u>

A detailed study was done on the Balance of System (BOS) for the Tucson Electric Power (TEP) Springerville, Arizona, PV plant (Mason et al., Progress in Photovoltaics, 2005). **Actual performance data over three years** were used, along with detailed mass and energy inventories. The TEP instituted an innovative PV installation program guided by optimizing the design and mimimizing cost. The resulting advanced PV structure incorporated the weight of the PV modules as an element of support design, thereby eliminating the need for concrete foundations. The estimate of the life-cycle energy requirements embodied in the BOS is 542 MJ/m^2, a 71% reduction from those of an older central plant; the corresponding life-cycle greenhouse gas emissions are 29 kg $CO_{2\text{-eq.}}$ /m^2. From field measurements, the energy payback time (EPT) of the BOS is 0.21 years at the actual location of this plant, and 0.4 years for average southern Europe insolation conditions (1700 kWh/m2-yr). The calculated CO_2 emissions during the life cycle of the BOS are **6 g/kWh** for 1700 kWh/m^2-yr solar inputs

<u>CdTe PV Modules and On-ground Utility Installations</u>

Fthenakis and Kim (MRS, Symposium on LCA, Nov. 2005) presented a detailed analysis of the CdTe PV lifecycle based on materials and energy data from a commercial 25 MW_p plant in Perrysburg, Ohio. The energy payback time of the system is 0.8 years, and the life cycle GHG emissions factor are 19 g CO_2-eq./kWh based on the current rated electric-conversion efficiency of 9%, Southern Europe insolation conditions (1700 kWh/m^2/yr), a lifetime of 30 years, and a system efficiency of 80%. In combination with the BOS for a central (utility) up-to-date system, the energy payback time and GHG emissions for this CdTe PV fuel cycle would be 1.25 years and **25 g CO_2-eq./kWh**, respectively, for the U.S. electrical mixture (less for the European electricity mixture)1. The external costs of the whole system are **0.13 €c/kWh**, based on ExternE base case damage factors (Table 1).

More progress is expected in the energy and emission factors of photovoltaic systems as production lines are optimized and scaled up.

Table 1. Damage Factors for External Costs of Photovoltaics in Europe and the United States

	Base Case	"---CRYSTAL CLEAR-----------				----BNL (CdTe+BOS)-----	
	Damage factor			S-Europe			External cost US
		Crystal Clear		CdTe	BOS	CdTe + BOS	
	(€-/ton)	(kg/MJ)	**(€c/kWh)**	(kg/MJ)	(kg/MJ)	(kg/MJ)	**(€c/kWh)**
CO2-eq	19	1.46E-02	6.50E-02	5.38E-03	2.08E-03	7.46E-03	5.10E-02
As	80000	1.31E-08	2.46E-04	4.05E-10	2.76E-09	3.17E-09	9.12E-05
Cd	39000	4.46E-09	4.07E-05	3.89E-10	7.07E-10	1.10E-09	1.54E-05
Cr	31500	1.76E-08	1.30E-04	9.86E-10	1.11E-08	1.20E-08	1.37E-04
Cr-IV	240000	4.31E-10	2.42E-05	1.66E-11	2.61E-10	2.78E-10	2.40E-05
Cr-other	0		0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Formaldehyde	120	1.85E-08	5.20E-07	3.57E-09	2.87E-08	3.23E-08	1.39E-06
Ni	3800	2.95E-08	2.63E-05	1.16E-09	5.30E-09	6.46E-09	8.83E-06
Nitrates, primary	5862	4.39E-11	6.03E-08	2.74E-11	1.05E-10	1.33E-10	2.80E-07
NMVOC	1124	5.98E-06	1.57E-03	5.38E-06	3.40E-06	8.78E-06	3.55E-03
NOx	2908	2.87E-08	1.96E-05	4.05E-13	1.31E-05	1.31E-05	1.37E-02
Pb	1600000	1.33E-07	4.99E-02	2.10E-08	1.69E-08	3.79E-08	2.18E-02
PM10	11723		0.00E+00	1.96E-11	1.04E-08	1.04E-08	4.39E-05
PM2.5	19539	4.09E-06	1.87E-02	8.78E-07	1.41E-08	8.92E-07	6.27E-03
PM2.5-10	0	3.63E-06	0.00E+00	3.22E-07	3.30E-06	3.62E-06	0.00E+00
SO2	2939	4.33E-05	2.98E-02	2.85E-06	2.49E-05	2.78E-05	2.94E-02
Sulfates, primary	11723	1.15E-07	3.16E-04	7.43E-08	2.29E-08	9.72E-08	4.10E-04
Radionuclide emissions	5000	4.21E-12	4.93E-09	7.79E-11	0.00E+00	7.79E-11	1.40E-07
Total			**0.165**				**0.126**